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Effect of building regulation on energy consumption in residential buildings in Korea

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ABSTRACT

According to the International Energy Agency (IEA), the energy demand for the building sector constituted about 25.3% of the final energy use in South Korea. The energy demand for residential buildings counts for 50.3% of the building sector and has also increased by 2.9 percent every year. The Korean government has shifted focus and is now promoting energy efficiency within the building sector and has set long-term energy conservation goals.

Despite these efforts to minimize building energy, the Korean government has changed the building regulation to allow remodeling of the balcony space as a living space. Remodeling the balcony space to become an indoor space means that a buffer space for the outdoor environment is lost, causing thermal discomfort and discomfort glare and moreover, increasing the heating and cooling energy demand in residential buildings. Also, it results in an increase in building energy demand in South Korea.

In this study, the effect of the alteration of balcony space on the indoor thermal environment and the heating and cooling energy demand of residential buildings in Korea were investigated by field measurement and simulation. From the measurement results, the indoor temperature of the condition without a balcony was 0.8 °C lower than that with a balcony. The heating and cooling load of the unit without the balcony space was 39% and 22% higher, respectively, than that of the unit with the balcony space. This increase results in considerable energy loss in the national scale and the ratio will be 0.3% of the final energy use in Korea. Also, it represents about 1.3% of the final energy use within the building sector of Korea.

Contents

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1. Introduction

Korea is the world's second largest importer of coal, and one of the largest importers of oil and natural gas [1]. In 2007, 516 Mt (Million metric tons) of carbon dioxide was emitted in Korea [1]. Also, according to the International Energy Agency (IEA), the building sector in Korea consumed 37.2 Mtoe, comprising about 25.3% of the final energy use in 2008. The energy demand for residential buildings counts for 50.3% of the building sector and has also increased by 2.9 percent every year. This is the highest growth rate among the energy consumption sectors in Korea, also among Asian Pacific countries [2]. The increase in the energy demands for the building sector is due to the rising need for office buildings and a higher level of dwelling comfort desired in residential buildings with the economic development of Korea. Also, increasingly more high-rise buildings are being constructed with the tendency of the population to migrate to the city.

The Korean government then issued standard requirements for building energy efficiency and set long-term energy conservation goals for the building sector. It set a goal of reducing emissions by 6%, compared with projected emissions, in the building sector by 2020 [3]. Also, beginning with the building standard on insulation thickness in 1977, the Korean government has put in place a comprehensive program to minimize building energy consumption, coupling mandatory standards with voluntary efforts in building energy labeling, a Green Building Certification program, and financial incentive programs [4].

Although the Korean government has made an effort to minimize building energy consumption, it has an ambivalent attitude to building regulations such as balcony remodeling in residential buildings. This results in substantial energy loss in the national scale in South Korea.

In Korea, it is estimated that more than 58.3% of the total residential buildings comprise apartment buildings, and most of these are high-rise structures with 15–30 stories [5]. Apartment units in Korea typically have a balcony along the outer wall at a width of 1.0–1.5 m. Windows are generally installed along the edge of each balcony [6]. Also, balconies fitted with windows act as a climate-filter where sun and daylight are admitted or rejected, where breezes and sounds are channeled or deflected, and where the rain is repelled or collected. In particular, windows installed on the edge of balconies occupy a major portion of the entire building facade, and therefore play an important role in the thermal performance of the façade in high-rise residential buildings.

However, according to the press of the Construction and Economy Research Institute of Korea (CERIK), up to 2009, in more than 2.6 million apartment units, the balconies have been expanded for living space. Remodeling the balcony space to become an indoor space means that a buffer space is lost, causing thermal discomfort and discomfort glare, and increasing the heating and cooling load and condensation on the surface of the walls and windows. Also, the changed policy for balcony space affects the total energy demand in South Korea. Therefore, the Korean government authorities have reinforced the standard for the heat transmission coefficient (U-value) of windows from 3.84 W/(m^2 K) to 3.0 W/(m^2 K) and have specified that window glass must be installed with double low-e or triple glazing in the case of balcony remodeling. Even though this building regulation is now being enforced, balcony alteration is still causing problems in residential buildings.

Some studies have been carried out to discuss the relation between building regulations (including standards, building codes, minimum requirements and energy standards) and energy demand or energy efficiency. Kjaerbye et al. evaluated the effect of building regulations that are aimed at increasing the efficiency of space heating energy use [7]. Jacobsen and Kotchen carried out an analysis to determine whether energy codes are an effective way to reduce energy consumption in practice. Their paper provides one of the first evaluations of an energy-code change using residential billing data on electricity and natural-gas consumption. Using data from Gainesville, FL, they found that the state's energy-code change that took effect in 2002 is associated with a 4 percent decrease in electricity consumption and a 6-percent decrease in natural-gas consumption [8].

Related to the effect of balcony space or envelope design on building energy demand, Chan and Chow [9] studied the energy and environmental impact due to the provision of a balcony for residential apartments in Hong Kong. They studied the effects of a balcony's orientation and window glazing material. Their report revealed that residential flats facing various orientations can offer substantial energy saving in the air-conditioning system due to the shading effect of the balcony. The building case with a south-west facing balcony and a clear glazed window gave the highest saving percentage of 12.3% in annual air-conditioning consumption. Raeissi and Taheri investigated the optimum dimensions of an overhang, including the width, lateral extension and spacing of overhangs, for energy saving in the air-conditioning system [10]. The results revealed that, under the climatic conditions in Iran, there was a reduction of around 12.7% in the cooling load during the summer season using appropriate overhang shading. On the other hand, there was an insignificant increase (0.6%) in winter heating demand. Florides et al. [11] examined the effect of measures to lower building energy consumption using the TRNSYS program for the modern houses in Cyprus. As measures to reduce the thermal load, they examined the cases of natural and controlled ventilation, solar shading, various types of glazing, orientation, shape of buildings, and thermal mass. It was found that a saving of 7–19% in annual cooling load could be achieved

Fig. 1. Illustration of the analyzed apartment building façade.

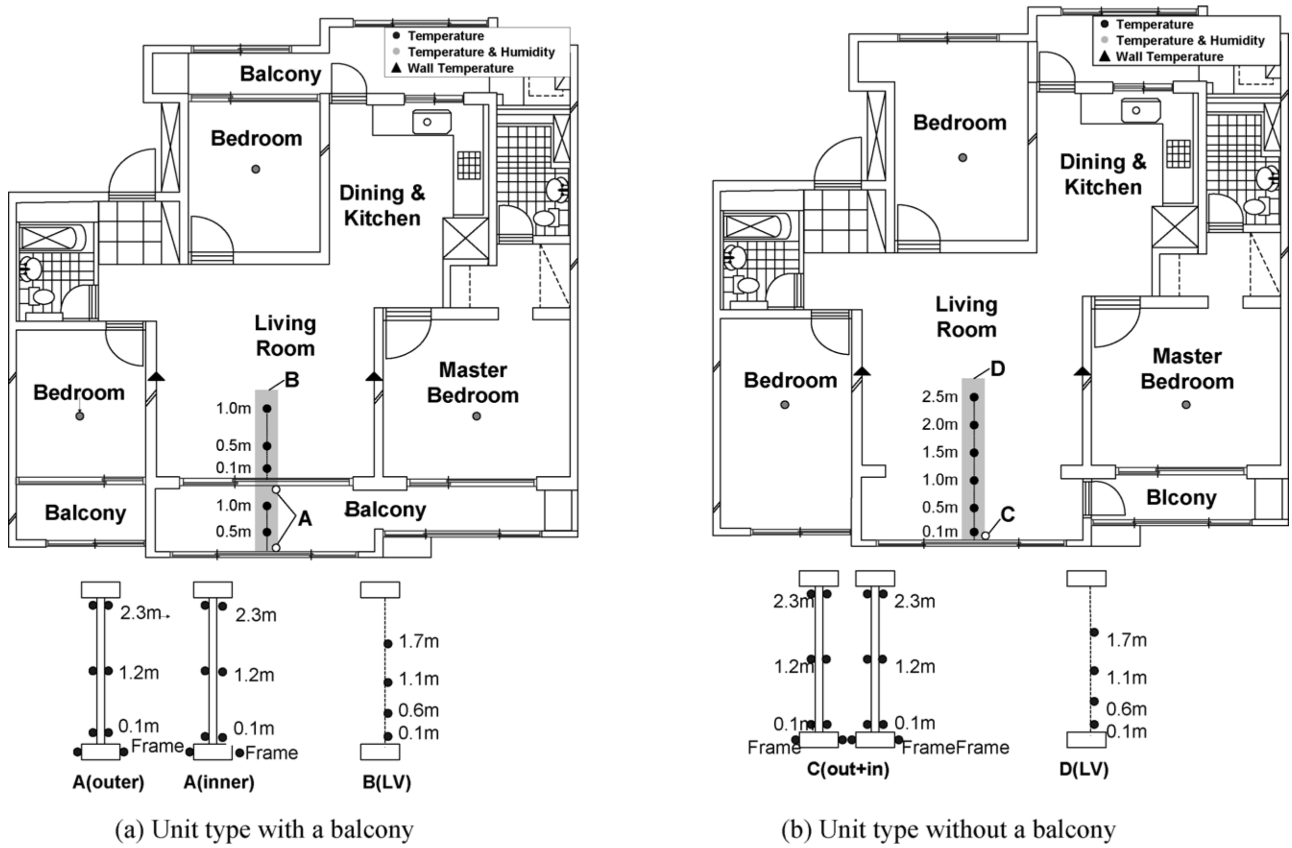

Fig. 2. Apartment unit plans for with/without a balcony space.

for a house constructed with a balcony and different insulation materials.

The aim of this study is to review the effect of the balcony space on indoor thermal environment and energy demand for heating and cooling in high-rise residential buildings in Korea using field measurements and simulation methods. Also, the impact of the balcony alteration on the energy loss on the national scale in Korea will be analyzed.

2. Methods

2.1. Field measurements

The indoor thermal environment for apartments with and without a balcony was evaluated through field measurement. Specifically, field measurement was conducted in two apartment units in a new 22 storey apartment building in Seoul, Korea; one apartment is on the 2nd floor (apartment unit with balcony) and one apartment is on the 5th floor (apartment unit without balcony) (Fig. 1).

Fig. 2 shows the floor plans of each house unit. The balconies were located along both sides of the building envelope in unit type with the balcony. The balconies on the front side were mainly adjacent to the living room, master bedroom and south facing bedroom. The rear side balconies were adjacent to the small bedroom and dining & kitchen areas, while the living room and bedroom of the front side directly faced the outdoor air in the apartment without the balcony. Also, the rear side bedroom directly faced the outdoor air.

In the apartment without the balcony, the inner and outer windows were both double glazed with 5 mm glass separated by a

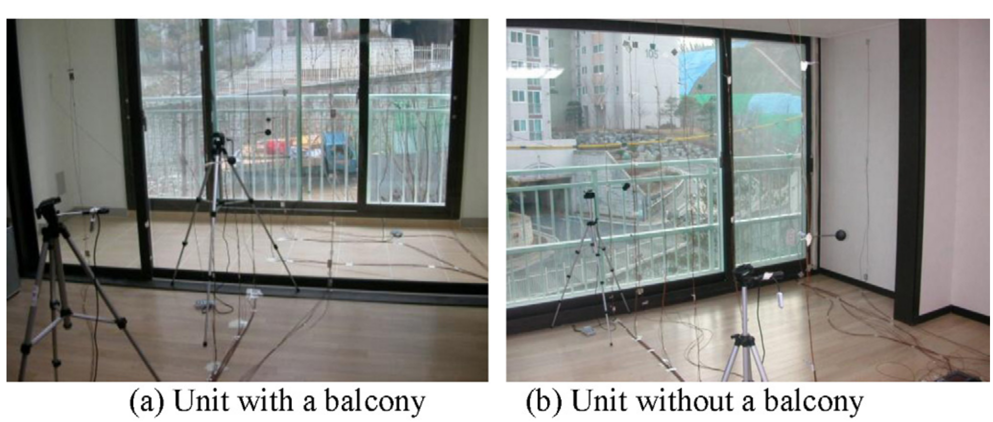

Fig. 3. Measurement scene.

6 mm air gap with an 89 mm air layer. In the apartment with the balcony, there was a 1330 mm balcony space between the outer window, which is double glazed with 6 mm glass separated by a 6 mm air gap, and the inner window, which is double glazed with 5 mm glass separated by a 6 mm air gap. The frame of each window was made of polyvinyl chloride (PVC).

Fig. 3 shows the measurement scene of the target apartment units. There were no occupants at the time of measurement. To assume that there were occupants, indoor heat was generated and a humidifier was also used. Measurements were conducted for 6 days from December 11 to 16, 2006, the coldest season in Korea. The main measurement target was the living room. To investigate the heat loss and indoor thermal environment characteristics of the apartments with and without a balcony, the window surface temperatures, indoor vertical and horizontal temperatures, indoor air current, relative humidity, and globe temperature were measured. Moreover, in order to estimate the incidence of condensation of the window surface and frame, which is one of the problems caused by balcony remodeling, these conditions were also measured in the living room and balcony space. Also, the air temperature and humidity of the center of each room were measured in both apartments as shown in Fig. 2. A weather station was also installed outdoors to measure the outdoor temperature and the humidity and wind speed during the field measurement period. The field measurement results were also used as input for the simulation. The characteristics of the measuring instruments followed class C in ISO 7726, which deals with the minimum characteristics of instruments to be used for the measurement of physical parameters [12].

2.2. Simulation

2.2.1. Simulation condition

To analyze the thermal performance of a balcony space and the impacts on heating and cooling energy demands, a simulation method was set up in this study as shown in Fig. 4. The simulation method is based on TRNSYS [13], coupled with Window5 [14] and Therm5 [15] to analyze the thermal characteristics of windows. This simulation evaluates the thermal performance of the balcony space, including the heat flow characteristics of the window system, the incidence of condensation, the indoor thermal environment such as indoor temperature change, thermal comfort, heating and cooling load and energy demand.

Simulation modeling to analyze the thermal performance of the balcony space and window system installed in the measured apartment units was conducted under the same conditions as the measurement conditions. The results obtained in the field measurement were used for the simulation, and the conditions are presented in Table 1. The amount of equipment and lighting heat per unit area are set as the same in both the unit with and without a balcony. Also, the number of occupants, 4 persons, is the same in both units (Table 2).

Table 3 shows the results of the thermal performance of windows in both apartments as conducted with Therm5 and Window5.

Table 1
Simulation conditions.

Weather data	Experimental data and SAREK weather data for Seoul, Korea [16]	
Location	Middle floor, adjacent house in the neighborhood	
Air-conditioned space (m^2)	Unit with a balcony	79.90 m^2
	Unit without a balcony	95.04 m^2
Heating set point	22 °C, 40% Humidity	
Cooling set point	26 °C, 60% Humidity	
Heat gain	Person: 4 person (seated, at rest)	Sensible heat: 60 W/person Latent heat: 40 W/person
	Lighting	Room: 10 W/m^2 Living room: 13 W/m^2
	Equipment	Room: 20 W/m^2 Living room: 23 W/m^2
Ventilation	0.7 ACH	

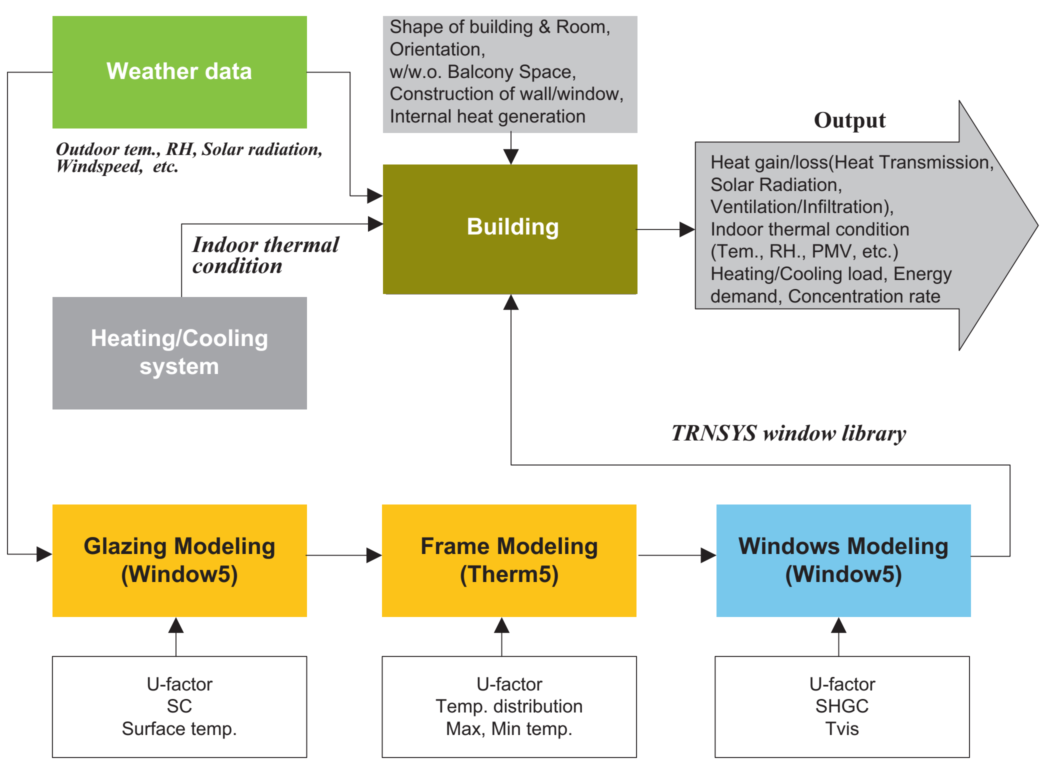

Fig. 4. Schematic diagram of thermal performance of balcony space by simulation.

Table 2
Schedules for simulation.

Heat gain	Location	Days	Time	Time	Value[a]	Heat gain	Location	Days	Time	Time	Value[a]
Person	Living + Dining + Kitchen	Weekday	0:00	5:00	0.3	Lighting	Living + Dining + Kitchen	Daily	0:00	0:00	0.5
			6:00	7:00	0.7				1:00	4:00	0.3
			8:00	18:00	0.4				5:00	6:00	0.6
			19:00	22:00	0.8				7:00	17:00	0.0
			23:00	24:00	0.3				18:00	18:00	0.5
		Weekend	0:00	1:00	0.4				19:00	19:00	0.7
			1:00	5:00	0.3				20:00	24:00	0.8
			6:00	7:00	0.6						
			8:00	13:00	0.7						
			14:00	17:00	0.5						
			18:00	22:00	0.7						
			23:00	24:00	0.4						
	Room 1	Weekday	0:00	5:00	1.0		Room 1	Daily	0:00	0:00	0.5
			6:00	6:00	0.7				1:00	4:00	0.2
			7:00	7:00	0.4				5:00	6:00	0.8
			8:00	17:00	0.3				7:00	16:00	0.0
			18:00	19:00	0.4				17:00	17:00	0.2
			20:00	21:00	0.6				18:00	18:00	0.5
			22:00	24:00	1.0				19:00	19:00	0.7
		Weekend	0:00	5:00	1.0				20:00	24:00	0.8
			6:00	6:00	0.7						
			7:00	7:00	0.4						
			8:00	14:00	0.3						
			15:00	17:00	0.4						
			18:00	21:00	0.6						
			22:00	24:00	1.0						
	Rooms 2	Weekday	0:00	6:00	1.0		Rooms 2	Daily	0:00	0:00	0.5
	and 3		7:00	7:00	0.5		and 3		1:00	4:00	0.2
			8:00	18:00	0.2				5:00	6:00	0.8
			19:00	21:00	0.5				7:00	16:00	0.0
			22:00	24:00	1.0				17:00	17:00	0.2
		Weekend	0:00	6:00	1.0				18:00	18:00	0.5
			7:00	7:00	0.5				19:00	19:00	0.7
			8:00	13:00	0.2				20:00	24:00	0.8
			14:00	17:00	0.5						
			18:00	21:00	0.7						
			22:00	24:00	1.0						
						Equipment	Living + Dining + Kitchen	Daily	0:00	4:00	0.2
							Rooms 1 and 3		6:00	6:00	0.4
									7:00	10:00	0.7
									11:00	12:00	0.6
									13:00	13:00	0.5
									14:00	16:00	0.4
									17:00	18:00	0.5
									19:00	20:00	0.6
									21:00	22:00	0.5
									23:00	23:00	0.4
									24:00	24:00	0.2

[a]Value: the ratio of resident = the number of current resident people/the number of whole set-up people.

Table 3
U-factor of windows with and without a balcony.

	Window with a balcony	Window without a balcony
Size (mm)	6/6/6/1330/5/6/5	5/6/5/89/5/6/5
Glazing U-factor (Window5)	(A1-A1′) 1.23 W/(m^2 K)	(B1-B1′) 1.74 W/(m^2 K)
Frame U-factor (Therm5)	(A2-A2′) 0.85 W/(m^2 K)	(B2-B2′) 0.89 W/(m^2 K)

The indoor and outdoor temperature conditions for analyzing the window thermal performance were set at 20 °C and 0 °C, respectively, based on the Korean Standard for Fenestration, KS F 2278 [17]. Based on the analysis results, if the balcony space is removed, the air layer between the windows shrinks. Thus, the *U*-factor of glass also increased considerably.

3. Results and discussion

3.1. Field measurement results

Fig. 5 and Table 4 show the field measurement results; these results were measured over two days from December 14 to 15 in 2006. The interior surface temperature of the window glass and frame and the changes in indoor temperature with the variation of the outdoor temperature were analyzed under conditions with and without a balcony. The outdoor temperature showed a range between 1 °C and 7 °C. Comparison showed that for the condition without a balcony, the indoor temperature was 0.8 °C lower than that with a balcony. Also, the surface and frame temperatures of the window were as low as 0.7 °C, 1.3 °C, respectively, for the condition without a balcony. Condensation was not reported in either of the apartment units over the measurement period. However, the possibility of a cold-draft was shown during night-time in the unit without a balcony.

3.2. Simulation results

3.2.1. Validation

To validate the simulation modeling, the field measurement results and simulation results were compared; similarly, these were compared for the indoor temperature and inner window surface temperature for the condition of the unit with a balcony.

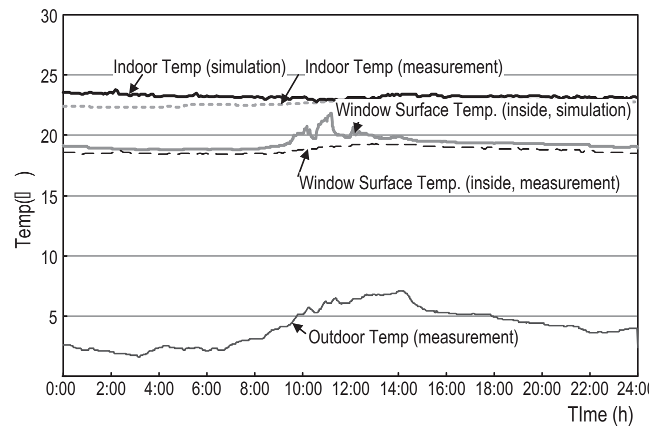

Fig. 6. Comparison between the simulation and field measurement results (December 15, 2006).

Because the effect of the balcony on the thermal environment of the building is so complicated, it can result in a difference between the real conditions and the simulation results. Therefore, simulation modeling for the balcony requires careful attention. As shown in Fig. 6, there was a slight difference in the simulation results and field measurement results; this difference was caused by solar radiation heat. Some solar shading occurred where the field measurements were conducted due to the surrounding buildings. The results were similar in general and the simulation modeling in this study can be said to effectively describe the thermal performance of the actual condition.

3.2.2. Effect of the balcony space on thermal environment

3.2.2.1. Incidence of condensation. The incidence of condensation of each window was calculated from November 15 to April 15 as the heating period. The period of incidence of condensation at the center of the glass surface was calculated based on an indoor temperature of 25 °C and relative humidity of 55%, which are the standard indoor conditions to calculate window surface condensation of a multi-residential house in Korea. As a result, as shown in Fig. 7, during the 3624 h of heating, there was no condensation in the unit with a balcony, yet condensation occurred for about 38 h (1.05%) in the unit without a balcony. This represents the incidence of condensation in the north room. In the south rooms,

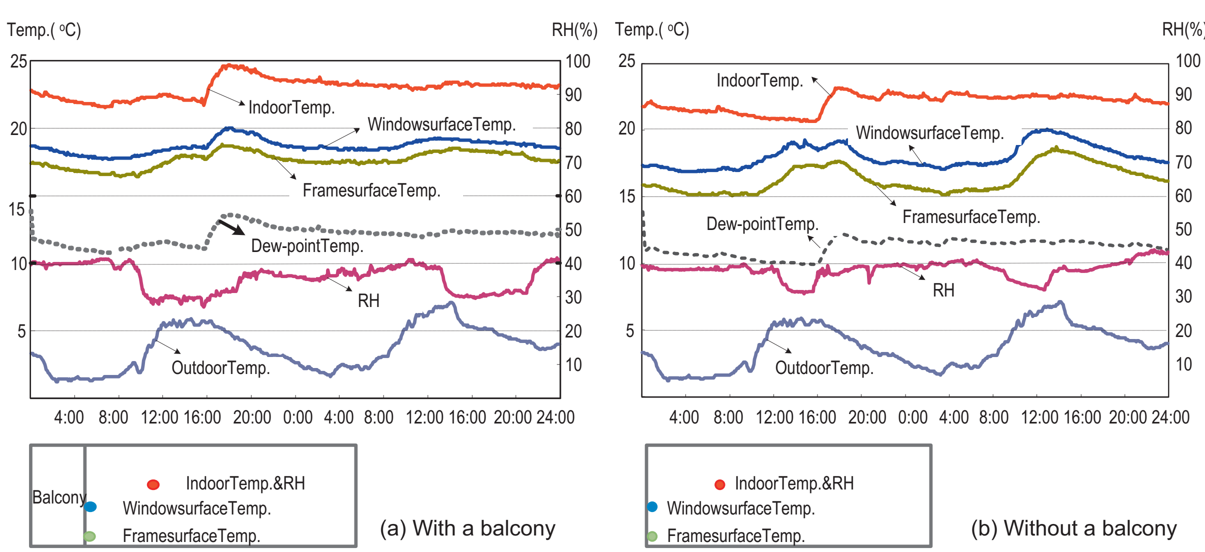

Fig. 5. Measurement results.

Table 4
Measurement results.

	Max	Min	Mean	STDEV
Unit with a balcony				
Outdoor temp.	7.1	1.2	3.7	1.5
Frame temp.	18.8	16.4	17.7	0.5
Win. surf. temp. (Edge (10 cm))	19.4	17.1	18.2	0.5
Win. surf. temp. (Center)	20.0	17.7	18.7	0.5
Indoor temp.	24.7	21.5	23.0	0.7
Dew-point. temp.	10.2	1.9	7.2	1.8
Unit without a balcony				
Frame temp.	18.8	15.1	16.4	0.9
Win. SURF. temp. (Edge (10 cm))	19.2	15.8	17.1	0.9
Win. surf. temp. (Center)	20.1	16.9	18.0	0.8
Indoor temp.	23.2	20.7	22.2	0.6
Dew-point temp.	11.2	4.1	9.1	1.6

condensation did not occur as a result of heat gain of the window surfaces due to sunshine.

3.2.2.2. Heating/cooling load. The heating and cooling load of each type of unit was analyzed during the heating (November 1–March 31) and cooling (June 1–September 30) periods. The ventilation rate is set at 0.7ACH, which is the ventilation standard of Korea. Also, the weather data used is the standard weather data of the Society of Air-conditioning and Refrigerating Engineers of Korea.

The results are presented in Fig. 8. The heating loads of the unit with a balcony and the unit without a balcony were 92 MJ/m^2 and 128 MJ/m^2, respectively. In the case of the unit without a balcony condition, the heating load was 39% higher than that of the unit with a balcony condition.

As shown in Fig. 8(a), the heating load caused by ventilation increased remarkably in the case of the unit without a balcony because the outdoor air directly enters the rooms. However, in the case of unit with a balcony, the heating load from ventilation was decreased by pre-heating the outdoor air in the balcony space. Although the heating load of unit without a balcony was decreased by solar heat in the winter, the load due to this has a relatively smaller effect compared to the load due to ventilation.

The cooling load of the unit with a balcony was 94 MJ/m^2, and that of the unit without a balcony was 115 MJ/m^2 or 22% higher than that of the unit with a balcony.

However, as shown in Fig. 8(b), the cooling load of the unit with a balcony was decreased by the block of solar heat owing to the shading effect of the balcony space, in contrast to the unit without a balcony, in which the solar heat directly flowed into the rooms. Even if the cooling load of the unit without a balcony is decreased by ventilation and the conduction of the walls at night-time, the effect is small.

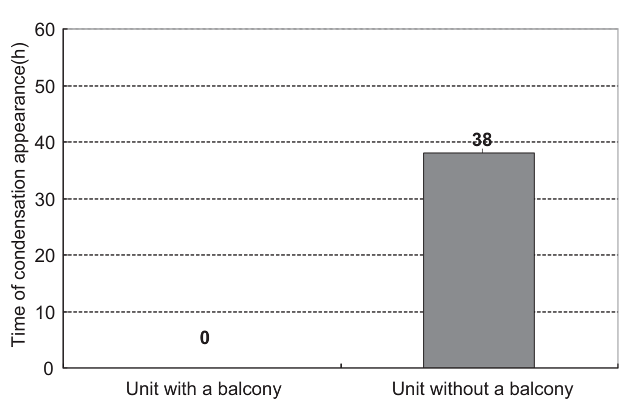

Fig. 7. Comparison of the incidence of condensation.

3.2.3. Effect of the balcony space on total energy demand in Korea

According to the press of the Construction and Economy Research Institute of Korea (CERIK), until now, of the 8.67 million apartment units in Korea, the balconies of more than 2.66 million apartment units have been remodeled as living space. The distribution of apartment units in Korea can be classified according to dimensions as shown in Fig. 9. Also, the ratio of annual heating and cooling energy changes of apartment buildings according to dimensions in Korea is shown in Fig. 10. These results were calculated by

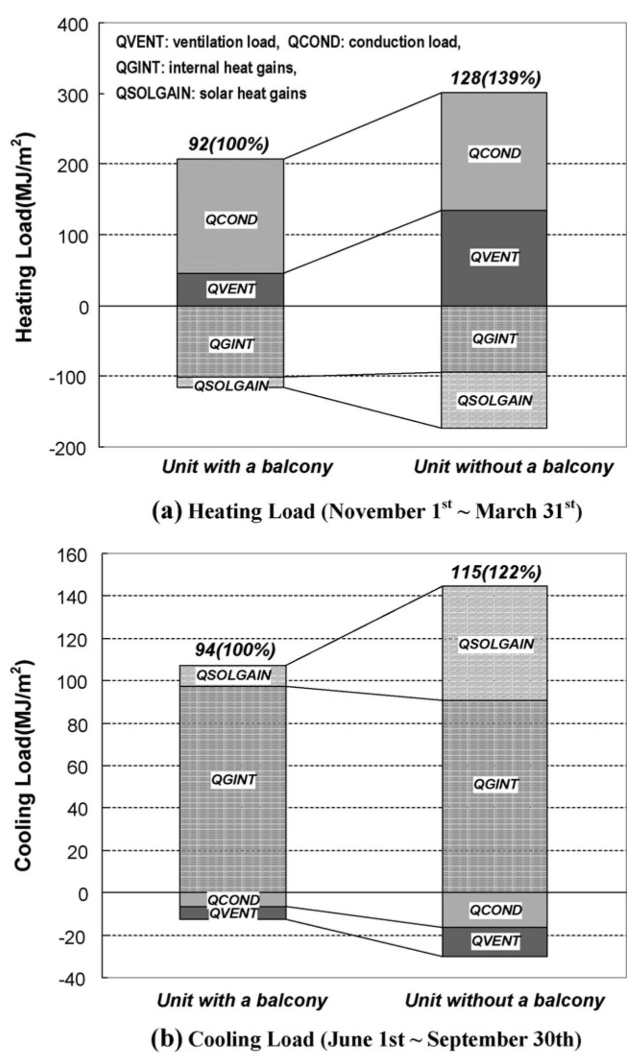

Fig. 8. Comparison of annual heating/cooling loads (MJ/m^2).

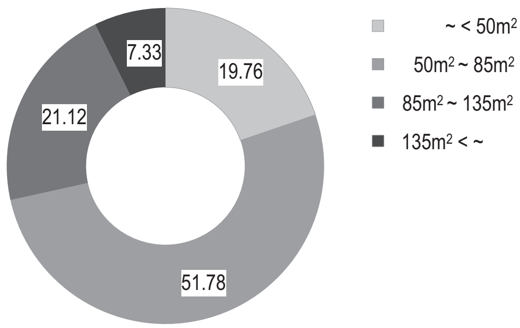

Fig. 9. Distribution of the apartment house according to dimensions in Korea (%).

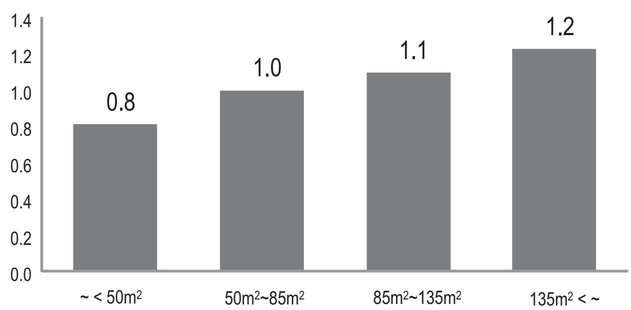

Fig. 10. Ratio of annual heating and cooling energy changes of the apartment buildings according to dimensions in Korea.

Table 5
Heating and cooling energy demand of the analyzed apartment with/without a balcony heating energy.

	Heating energy (GJ/year)	Cooling energy (GJ/year)	Total (GJ/year)
Unit with a balcony	7.35	7.51	14.86
Unit without a balcony	12.17	10.93	23.94

TRNSYS simulation and the ratio is based on the annual heating and cooling energy demand of an 85 m^2 unit. It was assumed that the heat gain and loss factors changed proportionally to the size of the unit based on the simulation condition in Table 1.

Scenario to calculate the average energy loss for without a balcony is as follows:

$$\text{Average energy loss for without a balcony}$$
$$= \sum(\text{energy loss of an 85 m}^2\text{ unit for without a balcony}$$
$$\times \text{ energy demand change rate according to dimensions}$$
$$\times \text{ distribution rate of the apartment unit according to dimensions})$$

Considering the results in Table 5, Figs. 9 and 10, the average annual energy loss for apartment units in Korea owing to balcony remodeling is 8.228 GJ/year*unit. Therefore, the total energy loss on the national scale in Korea caused by balcony alteration is as follows:

$$\frac{8.228\text{ GJ/apartment unit} \times 2,668,000 \quad [\text{total apartment unit}]}{42\text{ GJ/toe}}$$
$$= 522,673\text{ toe}$$

The total final energy use in Korea in 2009 was 182,065 ktoe [18]. Although this result was broadly evaluated, the energy loss originating from balcony alterations in apartment buildings in Korea may account for 0.3% of the total final energy use in Korea in 2009. Also, it constitutes about 1.3% of the final energy use in the building sector of Korea. This is an enormous loss on the national scale in Korea. This result shows that an erroneous policy has led to an enormous effect on the national energy demand.

4. Conclusion

In this study, to analyze the effect of the balcony space on the indoor thermal environment and heating and cooling load in high-rise apartment buildings in Korea, field measurement and simulation were accomplished. The simulation method was based on the existing TRNSYS program, coupled with Window5 and Therm5. From the field measurement results, the simulation results were compared with the measurement results in general.

In the results of the simulation, the heating and cooling load of the apartment unit without balcony were 39% and 22% higher, respectively, than the apartment unit with a balcony. This creates a significant energy loss on the national scale and the ratio will be 0.3% of the total final energy demand and 1.3% of the building sector in South Korea. According to the results, it was confirmed that an erroneous policy has created on enormous effect on the national energy demand.

To this end, the effect of building regulation or policy on energy demand should be considered before any action is taken.

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